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13. ABSTRACT (Maximum 200 words) Highlights of our progress include significant improvements in intensity and track predictions for hurricanes with the use of physical initialization techniques and very high resolution (T170) global and regional (T240) model forecasts using the FSU models. These improvements are supported by results of forecasts made for Hurricanes Erin and Opal of 1995 and Hurrican Fran of 1996.				
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Annual Technical Report

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Office of Naval Research Project N00014-95-1-1132

Project Title: Tropical Numerical Weather Prediction and Collaboration with the Naval Research Laboratory

Progress for Period: 07/01/96 - 06/30/97

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1. Test of a recently developed regional spectral model, Hurricane Erin

We have performed a case study for Hurricane Erin of the 1995 storm season using the recently developed Florida State University Nested Regional Spectral Model (FSUNRSM). The nested regional spectral model uses a perturbation technique similar to that used in the NCEP (National Center for Environmental Prediction) and ECMWF (European Center for Medium-range Weather Forecasting) regional spectral models, but with a number of differences, such as the use of a Mercator projection. The perturbations are deviations from the FSU Global Spectral Model (FSUGSM) results and are spectrally represented with π - periodic trigonometric basis functions. The perturbations are relaxed at the boundary to approach the global model results. We solve for the perturbation time tendencies using a semi-implicit time integration scheme similar to that used in the FSUGSM. The regional model has the same sigma-coordinate vertical structure and physics as FSUGSM. We include implicit horizontal diffusion and time filtering of the perturbations.

Erin made landfall on both the Atlantic coast and Gulf coast of Florida, each time with hurricane strength. We performed a 4-day prediction using a 0.5° transform grid, which yields an equivalent resolution to a T240 global model. T106 and T126 global models were used to provide base fields for the regional model as well as control experiments. The intensity forecast of the regional model was superior to that of the global model and reasonable close to the observed intensity. With physical initialization, the forecast track of the storm is improved in both

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the global and regional models. However, the regional model predicted the best track, showing both landfalls within 100km of the observed landfalls. This work is reprinted in Cocke (1997).

2. Forecast skill for many hurricane/typhoon forecasts.

We have calculated the forecast skill for the Florida State University Spectral Model (FSUGSM) for several tropical systems in the Atlantic and Pacific Ocean Basins and compared to operational forecast skill. The series of forecasts were initialized using global analyses and supplemental satellite data. Track forecasts errors were calculated for the storm series for control runs, enhanced runs, and operational forecasts made for the same time periods. Cumulative results for all modeled 1995 hurricanes are summarized. Overall, our study demonstrated that the FSU model performed better than the official JTWC and the NHC forecasts for tracks. This work is reported in Williford *et al.* (1997).

3. Analysis of the intensity forecasts for Hurricane Opal of 1995.

We have assimilated the formation of Hurricane Opal (1995) using the FSUGSM at very high resolution and interpreted factors contributing towards it. The assimilation makes use of a detailed physical initialization that vastly improves the nowcasting skill of rainfall and the model based outgoing long-wave radiation. Some of the interesting aspects of Hurricane Opal's history occurred between October 1, 1995 12 UTC and October 5, 1995 12 UTC. During this period the storm made landfall over the Florida Panhandle. The storm reached maximum wind speed of over 130 knots on October 4, 1995. The intensity issue of Opal has drawn much attention. Issues such as the potential vorticity impact from a middle latitude trough, the angular momentum of the lower tropospheric inflow layer, the warm ocean temperature anomalies of the Northern Gulf and the possible role of mesoconvective concentric eye wall are discussed in this paper.

The main finding of our study is that a reduction of the gradient of angular momentum occurs above the regions of maximum convective heating. This contributed towards stronger cyclonic spin-up of parcels that enter the storm environment from the middle latitudes. Another major contributor is the import of angular momentum along the lower tropospheric inflow channels of the storm. These channels were found to be open, i.e. uncontaminated with a plethora of deep convection and heavy rain. This permitted the high angular momentum to advance towards the storm's interior, thus contributing to its intensification. These results are reported in MWR, Krishnamurti *et al.* (1997a).

4. Ensemble forecasts from a large sample of analyses.

Ensemble forecasting of hurricane tracks is an emerging area in numerical weather prediction. We have studied the spread of the ensemble of forecast tracks from a family of different FGGE analyses. All forecasts start at the same date and use the same global prediction model. We have examined ensemble forecasts for four different hurricanes/typhoons of the year 1979. We have used eight different initial analyses to examine the spread of ensemble forecasts through six days from the initial state. A total of 16 forecasts were made, of which 8 of them invoked physical initialization. Physical initialization is a procedure for improving the initial rainfall rates consistent with satellite/raingauge based measures of rainfall. The main results of this study are that useful track forecasts are obtained from physical initialization, which is shown to suppress the spread of the ensemble of track forecasts. The spread of the tracks is quite large if the rain rates are not

initialized. The major issue here is how one could make use of this information on ensemble forecasts for providing guidance. Towards that end we provide a statistical framework that makes use of the spread of forecast tracks to provide such guidance. These results appear in Krishnamurti *et al.* (1997b).

5. Ensemble forecasting of hurricane tracks.

Because of initial data uncertainties, it is inevitable that operational hurricane track forecasting would, in the future, follow an ensemble forecast approach. The ensemble technique is becoming increasingly popular for middle latitude weather forecasts. Our research focuses on an ensemble forecast methodology for the hurricane track forecast procedure.

In our study, an ensemble perturbation method is applied for hurricane track predictions using the Florida State University's Global Spectral Model (FSUGSM) with horizontal spectral resolution of T63 and 14 vertical levels.

The method is based on the premise that a) model perturbation grows linearly during the first few days of model integration; and b) in order to make a complete set of ensemble perturbations of hurricane forecasts, both intensity and position of the hurricane need to be perturbed.

The initial position of the hurricane is perturbed by displacing its original position 50km equally toward the north, south, east, and west directions. The fast growing intensity perturbations can be generated by implementing EOF analysis to the differences between forecasts starting from regular analysis and randomly perturbed analysis. Only the temperature and wind fields are perturbed with the order proportional to the respective observational error. The method generates fifteen ensemble members for each hurricane.

Our results demonstrate that this ensemble prediction method leads to an improvement in the hurricane track forecasts. The track position errors are largely reduced by the ensemble prediction for most of the hurricane cases that have been tested, and these forecasts are superior to the results from single model control experiments. We also note that the spread of the ensemble track forecasts is useful to assess the reliability of the predictions. These results appear in Zhang (1997).

6. Hurricane Fran 1995.

Starting with a new stream of very high resolution modeling that includes: a) Physical initialization; b) regional spectral modeling; and c) ensemble forecasts, we have noted that the skill in intensity forecasts (after an initial spin up) improved considerably. The tracks and intensity forecasts shown in the enclosed diagram showed skills higher than the official NHC and the GFDL forecasts.

T.N. Krishnamurti ONR Research related publications for 1996-97.

Cocke, S., 1997: Case Study of Erin using FSU Nested Regional Spectral Model. To appear in *Mon. Wea. Rev.*

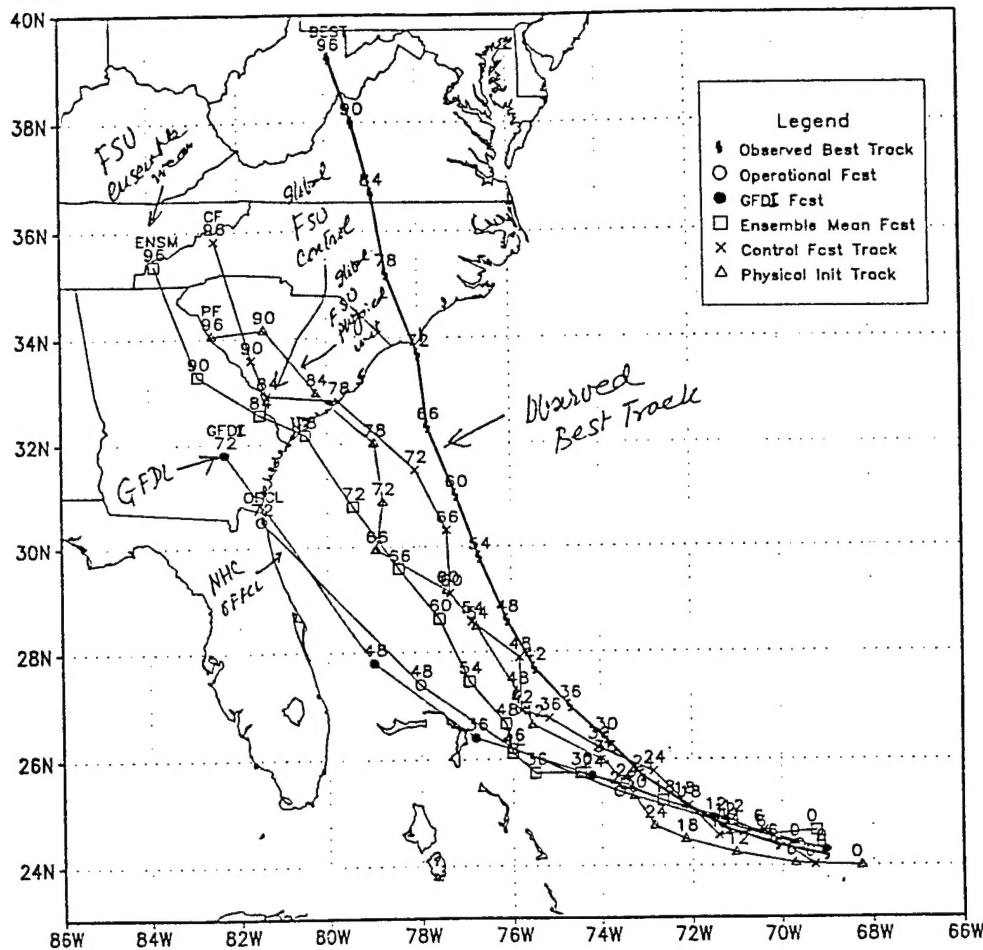
Krishnamurti, T.N., W. Han, B. Jha and H.S. Bedi, 1997a: Numerical Prediction of Hurricane Opal. To appear in *Mon. Wea. Rev.*

Krishnamurti, T.N., R.C. Torres, G. Rohaly and D. Oosterhof, 1997b: Physical Initialization and Hurricane Ensemble Forecasts. To appear in *J. Weather and Forecasting*.

Williford, C.E., R.C. Torres and T.N. Krishnamurti, 1997: A Note on Tropical Cyclone Forecasts Made with the FSU Global Spectral Model. To appear in *Mon. Wea. Rev.*

Zhang and T.N. Krishnamurti, 1997: On Ensemble Forecasting of Hurricane Tracks. To appear in *Bulletin of the American Meteorological Society*.

Hurricane Fran 1996 96HR Fcst 09/03 00Z



FRAN 96090300 Intensity Chart

96 hour Forecast

